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DRINKING WATER CRITERIA DOCUMENT FOR ENTEROVIRUSES AND HEPATITIS A: AN ADDENDUM

Prepared for

Health and Ecological Criteria Division
Office of Science and Technology
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FINAL DRAFT

Drinking Water Criteria Document For Enteroviruses (Poliovirus, Coxsackie group A and B, Echovirus, Enterovirus Type 68, 69, 70 and 71) and Hepatitis A. EPA/822/R/98/043

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1.0 Executive Summary

The Office of Science and Technology (OST) has prepared and revised the Drinking Water Criteria documents that will support the Office of Water's Ground Water Rule (GWR) and Surface Water Treatment Rule (SWTR). Waterborne pathogenic enteric viruses are among the microorganisms to be regulated by these rules. The SWTR requires water systems that use surface or ground water that is under the direct influence of surface water to (a) disinfect their water and (b) filter their water or meet criteria for avoiding filtration. Under this rule viruses must be removed or inactivated at a 99.99% (4 logs) level by meeting the residual concentration and disinfectant contact time values in the rule.

Four of the enteric viruses, namely, coxsackievirus, echovirus, calicivirus, and adenovirus, have also been included among the microorganisms of concern on the Environmental Protection Agency (EPA) Drinking Water Contaminant Candidate List (CCL). The Safe Drinking Water Act (SDWA) amendments of 1996 require EPA to publish a list of contaminants, which at the time of publication are not subject to any proposed or promulgated national primary drinking water regulation (NPDWR), that are known or anticipated to occur in public water systems and which may require regulations under the SDWA [section 1412(b)(1)].

The enteric viruses are viruses that multiply in the gastrointestinal (GI) tract of man. These viruses have been shown to cause a variety of diseases in humans, ranging from poliomyelitis, to heart disease, encephalitis, aseptic meningitis, hepatitis, hand-foot-and-mouth disease (HFMD), gastroenteritis, and diabetes mellitis. Enteric viruses are excreted in the feces of infected humans in numbers as high as 10^6–10^{12}/gram of feces.

A drinking water draft criteria document on enteric viruses was originally developed in 1985. The document now has a 15-year gap in information on the current scientific knowledge concerning waterborne pathogenic viruses. An updated virus criteria document is essential for the preparation of EPA's notice of availability to the stakeholders, states, and the general public, since this document will support the GWR and SWTR mentioned above.

Two drinking water criteria documents for viruses (EPA/822/R/98/042; EPA/822/R/98/043) have been developed by EPA to update information in the original criteria document. These documents contain new and updated information on various aspects of our current knowledge of waterborne enteric viruses, including their occurrence in source waters and sewage, outbreaks, health effects, minimum infectious dose, risk assessment, recovery and detection methods, and treatment control. The first of these documents (EPA/822/R/98/043) addresses the enteroviruses including: ***poliovirus, coxsackievirus group A, coxsackievirus group B, echovirus, enterovirus types 68, 69, 70, 71,*** and ***hepatitis A (formerly enterovirus type 72),*** which recently has been transferred to a newly created genus, called ***Hepatovirus.*** The second virus document (EPA/822/R/98/042) addresses eight other waterborne enteric viruses: ***adenovirus, astrovirus, reovirus, rotavirus, calicivirus,*** including ***Norwalk virus, small round structured viruses (SRSVs),*** and ***hepatitis E virus.***

The present document (EPA/822/R/98/043) addresses enteroviruses and hepatitis A and has been organized in 11 chapters. The table of contents outline from the 1985 document was followed for ease of cross-reference, although a few redundant topics were eliminated. A new chapter on water treatment has been added. The reader should note the difference between two terms, ***enterovirus*** and ***enteric virus,*** used throughout this document. The terms are not interchangeable, i.e., all enteric viruses are not enteroviruses. An enteric virus is defined, functionally, as a virus that multiplies in the GI tract of humans. All of the 12 waterborne viruses which are the subject of the two drinking water criteria documents are enteric viruses. An enterovirus belongs to a subgroup of enteric viruses in the genus *Enterovirus* that share similar morphological and genetic properties.

All of the enteroviruses, along with hepatitis A viruses, are shed in human feces and therefore occur in domestic sewage. There are numerous reports of their occurrence in both waste water and waste water-contaminated surface water. Outbreaks and epidemics have been associated with the presence of enterovirus in water with serious worldwide consequences. Both surface and ground water contamination have been linked to many of these outbreaks involving gastroenteritis and other illnesses. Reports indicate that most of the reported waterborne outbreaks have been associated with ground water even though this source had been believed to be relatively free from contamination due to natural filtration by soil layers, which act as barriers to microbial pollutants. Virus migration has been demonstrated in the soil subsurface for distances of 1,000 m or more, facilitating virus contamination of aquifers that provide drinking water to the public. EPA studies, as well as several others, indicate that a significant number of ground water sources show evidence of fecal contamination. This is the principal rationale for the requirement for ground water disinfection under the GWR.

The discussion on outbreaks addresses those occurring primarily in the United States. Many of these outbreaks have been shown to be associated with waterborne transmission. Waterborne disease outbreaks in the United States associated with treatment deficiencies in water supply have also been reported. When such deficiencies lead to EPA "boil water" advisories for sensitive subpopulations, as happened in the Washington, DC, area recently, consumer confidence in our water supply can be eroded, thereby increasing the number of consumers who turn to bottled water as a drinking water source, even after the treatment deficiencies are corrected.

There is a worldwide distribution of waterborne disease outbreaks. Some devastating outbreaks occurring outside the United States, and outbreaks in countries with treatment systems similar to those of the United States, are also discussed. Outbreak reports are not comparable as there were numerous reports retrieved for this document concerning waterborne outbreaks occurring in developing countries having insufficient or no treatment control systems. It has been estimated that the occurrence of enteric viruses in sewage in developing countries may average 100 to 1,000 times higher than levels seen in the United States. This document therefore notes only a few of the outbreaks from developing countries, but discusses the health effects known to occur worldwide regardless of treatment control systems.

It is important, however, that we remain cognizant of the fact that outbreaks outside of the United States can have worldwide implications, particularly in light of increased global cooperation and interactions. International travel is increasing, and it is conceivable that viruses can be exported rapidly across country borderlines by infected travelers. In addition, the escalating influx of immigrants from developing and war-ravaged countries having inadequate treatment systems is an important factor in the spread of imported waterborne viral diseases. With the United States the only superpower remaining in the world, American troops are being sent on peacekeeping missions around the world. A global partnership and collaboration with developing countries regarding waterborne outbreaks is needed to rapidly identify emerging or reemerging strains of infectious pathogens that could pose a threat both to the United States and to the world at large.

The problem of waterborne diseases continues to be exacerbated by the high percentage of acute gastrointestinal illness (AGI) of unknown etiology. It is of significant concern that close to 50% of all waterborne disease outbreaks in the United States are due to AGI caused by unknown agents. Given isolation method limitations, it is reasonable to speculate that some of the AGI of unknown origin may very well be due to viruses. There is a speculation that the unknown etiological agents may be of viral origin, because the disease patterns support this speculation. But the evidence for this is inconclusive. Technological methods for bacteria are well established, and bacteria are well known and can be easily detected. The detection of viruses, on the other hand, is difficult and complex.

The U.S. Centers for Disease Control and Prevention (CDC) indicates that the number of reported waterborne disease outbreaks represents only a fraction of the total number. It is not surprising that waterborne disease outbreaks are grossly under-reported, especially when one examines the CDC criteria for an outbreak. In order to be recorded an outbreak, two or more persons must experience a similar illness after the consumption of or use of water intended for drinking. Epidemiological evidence must implicate water as the source of illness. Factors that have been listed as contributing to the nonreporting of outbreaks include budget and laboratory resources, lack of physician interest, and consumer awareness. Another factor to consider is embarrassment. Many affected people may be unwilling to talk about a little “diarrhea” episode that may disappear in a few days. Since only two people need manifest symptoms to be considered an “outbreak,” it is likely that embarrassment may account for a significant number of cases that go unreported. Therefore, a decrease in reported outbreaks may not be an actual decrease. A better surveillance system obviously is needed at the local level to accurately track outbreaks.

The awareness of virus occurrence in water has increased with the improvements in technology for viral recovery. This in turn has led to greater concerns regarding implications of virus presence in water. In monitoring waterborne viruses, a major problem has been the concentration and enumeration of large volumes of virions in raw and finished water. Because of their small size and low numbers, accurate assessments have been difficult. Detection of viruses in water sample volumes ranging from a few to 100 liters has remained a major challenge. Virus recovery methods in existence prior to 1985 include filter adsorption-elution, adsorption to inorganic precipitates, polyelectrolytes, minerals, clays, glass beads, ultrafiltration, hydroextraction, and reverse osmosis. Since that time, continuous immunomagnetic capture, continuous flow centrifugation, cross-flow filtration, and vortex flow filtration have emerged as new technologies for improved virus recovery. The efficiency of these methods, however, varies from 20% to 80%, even when relatively high concentrations of virions are present in water samples. With those percentages of variability in recovery, human risk associated with finished drinking water sources becomes more daunting in light of the fact that infective doses for human enterovirus infection could be as low as one to four infectious particles.

Selective and sensitive immunological methods for virus detection have emerged recently, but they are frequently time consuming, require specialized training, and are labor intensive. Cell culture methods, although available for several decades and a proven way for determining the infectivity of viral particles, are also slow, require specialized training, and are labor intensive. In addition, some waterborne viruses such as coxsackieviruses and Norwalk virus still cannot be cultivated or grow poorly in cell culture. New cell lines need to be investigated and developed for noncultivatable viruses.

The greatest improvements in environmental virology during the past 15 years have been in the development of virus detection methods. Polymerase chain reaction (PCR) reverse transcriptase (RT) methods in combination with other molecular technologies, however, have been developed with high specificity and sensitivity, and are proving to be very useful in the detection of all known pathogenic, waterborne viruses. Previously identified and classified microorganisms are being reassessed by molecular methods and reclassified into new genera, and unidentified microorganisms are being identified and classified based on their genomic sequences. However, the PCR method is very difficult to use with environmental samples because of inhibitory substances that interfere with the detection of viral nucleic acid. PCR, unlike the cell culture method, cannot distinguish between infectious and noninfectious particles.

As we approach the next millennium, a rising world population and its increasing demand for water have led to greater use of recycled waste water. The use of this resource, which may contain inactivated viruses, for agricultural purposes and for other human activities, has increased the risk of viral contamination of drinking water supplies. Enteroviruses have a low infectivity and it has been shown that 1–4 tissue culture infective doses can infect a person with a high probability. If this is the case, there is reason for great concern for the hazard posed by the occurrence of infectious pathogenic virus in drinking water.

The disease states of enterovirus infections are varied. They include poliomyelitis, infectious hepatitis, aseptic meningitis, heart diseases (pericarditis, myocarditis, myopericarditis, cardiomyopathy, ischemic heart disease), hand-foot-and-mouth disease (HFMD), gastroenteritis, and insulin-dependent diabetes mellitus. It is important to understand the health effects of these viruses and the resulting implications for public health. Therefore, the health effects chapter of this document presents as much evidence as is available on the general disease profiles of all the enteroviruses.

The manifestations of disease caused by waterborne viruses reflect the virulence of the particular pathogenic viral strain and the corresponding susceptibility of the infected host. Individuals with a depressed immune system, such as immuno-suppressed patients (cancer patients, organ transplant patients, AIDS patients), the elderly, and very young children, are generally at a higher risk than the normal population to infections and are consequently prone to more severe attacks and manifest the most severe symptoms. Apparent (showing clinical symptoms) and inapparent (lacking clinical symptoms) infections by enteric viruses have been demonstrated, and both must be recognized as asymptomatic individuals may continue to shed viruses in their feces and consequently infect others. The host defense systems are directly involved in determining whether the infection becomes clinical or subclinical and whether the individual may be subject to reinfection.

New approaches to microbial risk assessment by ILSI have been developed within the last few years that differ significantly from the National Academy of Sciences (NAS) framework for chemical risk assessment. Differences include pathogen-host interactions, secondary spread of microorganisms, short-term and long-term immunity, the carrier state, host animal reservoirs, zoonotic transmission, person-to-person transmission, and conditions that lead to survival, and multiplication of microorganisms (bacteria) in the environment. Various available risk models assume a random distribution of pathogenic microorganisms in water. The risk assessment of enteric viruses is limited because of lack of information on dose-response, occurrence, and exposure data. This document identifies a more quantitative risk approach for coxsackievirus type B4.

There is a question as to whether the standard bacterial indicator of fecal contamination in drinking water has outgrown its usefulness. This is because there have been numerous instances in which bacteriological drinking water standards have been met and yet gastroenteritis outbreaks due to viruses have occurred. The best indicator for the presence of pathogenic microorganisms is the pathogenic microorganism itself. However, testing for every pathogenic microorganism of concern is not feasible because pathogenic human viruses are not always easy to detect, and methods for their detection may be expensive and require specialized equipment and skilled technicians. Over the years, various alternative indicators have been proposed, such as bacteriophages, heterotrophic bacteria, *Clostridium, Klebsiella,* and *Bifidobacteria*. There is as yet no evidence that any one of the alternatives can effectively replace *E. coli* as the indicator of human fecal contamination. A surrogate for human viruses has not as yet been identified. The role that bacteriophages will play as viral indicators in the future is not clear at this time. Various studies show little correlation between the presence of bacteriophage indicators and the human viruses of concern. More research is needed to assess indicators for human viruses.

Viruses have been shown to be more resistant to treatment than bacteria. Chlorination has been the disinfection method of choice in the United States for the past several decades because of its effectiveness in destroying pathogenic microorganisms, but we now know that not all waterborne viruses are killed or inactivated by chlorine residuals commonly used for drinking water (up to 3.75 mg/L). At the same time, cancer risks associated with disinfectant byproducts such as trihalomethane have become a public health concern. Lower chlorine levels will decrease the risk posed by chlorination byproducts, but will increase the risk posed by pathogenic viruses. Conversely, an increase in chlorine concentration will reduce the risk posed by resistant pathogenic viruses but will greatly increase the risk posed by cancer-causing disinfectant byproducts. The question then becomes, ***Which risk do we trade for the other?***

Some of the effective alternative disinfection methods include chloramine, chlorine dioxide, ozonation, and UV light. Ozonation and UV light do not leave residuals to protect against recontamination events. However, chlorine continues to be the disinfection of choice in the United States.

2.0 General Information and Properties

2.1 Introduction

Viruses are obligate intracellular parasites that cannot replicate outside a host cell. Enteric viruses, however, have the ability to survive in the environment for extended periods of time. Of all the classified viruses, over 120 of them including all the enteroviruses and hepatitis A, multiply in the human GI tract. These enteric viruses are excreted by infected individuals into domestic sewage (Metcalf et al., 1995). The discharge of treated and untreated sewage into rivers and streams impacts surface waters, recreational waters, water intakes, lakes, oxidation ponds, and even shellfish beds in estuaries. Studies have shown that sewage discharge onto land can result in virus contamination of ground water. Viruses have been recovered from rivers, water intakes, and ground water that were miles away from where the initial release into water or on land had occurred. As a consequence of these discharges, disease outbreaks associated with viruses occur at frequent intervals. The type and concentration of enteric viruses present in the sewage are dependent on the community, disease incidence, water treatment, seasonality, and socioeconomic factors.

2.2 History and Taxonomy

Enteroviruses are classified as a genus within the family Picornaviridae by the International Committee on the Taxonomy of Viruses (ICTV) (ICTV, 1995). The criteria used by the ICTV for the official taxonomy of all classified viruses include morphology (shape, size, and presence or absence of envelope), nucleic acid type (RNA or DNA), and host range (human, animal, plant, fish, or bird).

The name enterovirus is derived from "entero" (intestine), the primary site of attack for these viruses. The enterovirus genus is made up of poliovirus; coxsackievirus group A; coxsackievirus group B; echovirus; enterovirus types 68, 69, 70, and 71; and several enteroviruses of lower animals, such as pigs, mice, monkeys, and cattle. Over 100 serotypes of enteroviruses have been recognized (Melnick, 1996a).

HAV, provisionally classified as enterovirus type 72, has now been transferred into a newly created genus called ***Hepatovirus*** (ICTV, 1995). The basis for this transfer involves differences in the amino acid sequence of the protein coat and the increased resistance of hepatitis A to thermal inactivation (Melnick, 1996a).

The enteroviruses share similar properties. They reside in the same habitat, the intestinal tract of humans, and are resistant to laboratory disinfectants such as alcohol and phenol. Various solvents and detergents known to destroy other viruses such as ether and deoxycholate are ineffective against enteroviruses (Melnick, 1996a).

The antigens of the enteroviruses are used to identify specific serotypes (Melnick, 1996b). However, Prabhakar et al. (1982) reported that antigenic mutations of enteroviruses are frequent, and as high as 1 per 10,000 virions. All known enteroviruses are resistant to all known antibiotics and chemotherapeutic agents (Melnick, 1996a). Enteroviruses are thermolabile and are rapidly destroyed when exposed to a temperature greater than 50°C. Thermal inactivation of enteroviruses has been shown to be inhibited by magnesium chloride (Melnick, 1996a,b). Poliovirus is protected against thermal inactivation in the presence of magnesium chloride, and the property has been used to stabilize oral poliovirus vaccines (Melnick, 1992).

The morphological characteristics of all the enteroviruses and hepatitis A are similar by electron microscopy (EM). As a result, an electron micrograph of poliovirus can be used to represent the morphology of any enterovirus member (Williams, 1998). The characteristics of all the enteroviruses and hepatitis A are summarized in Table 2-1.

2.2.1 Poliovirus

Poliovirus is the best known and the first recognized member of the enteroviruses. It has also been one of the most studied enteroviruses in part because it produces poliomyelitis, a devastating paralytic disease of humans. The history of poliovirus is a long one, and recently was reviewed chronologically by Melnick (1996a), one of the pioneers in the elucidation of this virus since its recovery from New York City sewage in the 1940s (EPA, 1985). The work of Melnick and Sabin has contributed to our understanding of poliovirus (Melnick, 1996a).

Three serotypes have been recognized, and poliovirus type 1 is the type species for the enterovirus genus (ICTV, 1995).

2.2.2 Coxsackievirus Group A

Coxsackievirus group A is one of two groups of coxsackieviruses that have been described. Coxsackievirus group A was first discovered by Dalldorf in 1948, and it derives its name from Coxsackie, a town in New York, where it was first isolated from a patient (Melnick, 1996a). There are 23 recognized serotypes of coxsackievirus group A (ICTV, 1995).

TABLE 2-1
Characteristics of Enteroviruses and Hepatitis A Virus

Enteroviruses						Hepatovirus
Virus	**Poliovirus**	**Coxsackie group A**	**Coxsackie group B**	**Echovirus**	**Enterovirus types 68, 69, 70, 71**	**Hepatitis A virus**
Number of serotypes	3	23	6	31	4	1
Genome	ssRNA	ssRNA	ssRNA	ssRNA	ssRNA	ssRNA
Size	27–30 nm	27–30 nm	27–30 nm	27–30 nm	27–30 nm	27 nm
Capsid	60 subunit icosahedron	60 subunit icosahedron	60 subunit icosahedron	60 subunit icosahedron	60 subunit icosahedron	60 subunit icosahedron
Virion	unenveloped	unenveloped	unenveloped	unenveloped	unenveloped	unenveloped
Buoyant density in CsCl	1.33–1.45 g/cm^{-3}	1.33–1.45 g/cm^{-3}	1.33–1.45 g/cm^{-3}	1.33–1.45 g/cm^{-3}	1.33–1.45 g/cm^{-3}	1.33–1.45 g/cm^{-3}
Morphology	featureless	featureless	featureless	featureless	featureless	featureless

Source: Williams, 1998; ICTV, 1995; Melnick, 1992, 1985.

2.2.3 Coxsackievirus Group B

Coxsackievirus group B was discovered by Melnick and was first isolated from a patient in Connecticut (Melnick, 1996a). It was described in 1949, a year after the discovery of coxsackievirus group A. Coxsackievirus group B has six recognized serotypes (ICTV, 1995).

2.2.4 Echovirus

Echovirus derives its name from the acronym of its full name, ***Enteric Cytopathogenic Human Orphan*** virus. Thirty-one echovirus serotypes have been described, and they are numbered sequentially from 1 through 31. Three of the serotypes have been reclassified. Echovirus type 10 has been reclassified as a reovirus, and type 28 has been reclassified as a rhinovirus. Echovirus type 34 is reclassified as a variant type of coxsackievirus A 24 (Melnick, 1996a).

2.2.5 Enterovirus Types 68, 69, 70, and 71

New members of the *Enterovirus* genus are no longer subclassified as coxsackievirus or echovirus but instead numbered sequentially because of the variability in the biological properties such as the production of pathological changes in newborn mice. This numerical numbering system will be retained for these enteroviruses until sufficient and definitive data become available to place them into an appropriate subgroup (Melnick, 1996a; Kibrick, 1964).
Only one serotype has been recognized for each numbered enterovirus (ICTV, 1995).

2.2.6 Hepatitis A Virus

HAV was formerly classified as enterovirus type 72 in the genus *Enterovirus*. It is now classified in the genus *Hepatovirus*. HAV shares many properties with all the viruses in the name from Coxsackie, a town in New York, where it was first isolated from a patient (Melnick, 1996). There are 23 recognized serotypes of coxsackievirus group A (ICTV, 1995). *Enterovirus* genus (see Table 2-1). It is, however, more temperature and acid stable than the enteroviruses. An HAV particle is 27 nm in diameter, is nonenveloped, and has an icosahedral symmetry. It has a single-stranded RNA genome that contains 7,500 nucleotides. The RNA strand is positive and thus serves as its own messenger RNA (Levinthal and Ray, 1966). Only one serotype has been described for hepatitis A (ICTV, 1995).

2.3 Viruses in Water

2.3.1 Sources of Viruses in Water

Human enteric viruses are excreted in high numbers (10^8–10^{12} particles/g of feces) by infected individuals and consequently are present in waters contaminated by fecal material (Abbaszadegan et al., 1998; Abbaszadegan and DeLeon, 1997; Payment, 1993). Treated waste water effluent from sewage treatment plants contains inactivated as well as infectious viruses that are discharged into surface water (Tani et al., 1995; Black and Finch, 1993; Bosch et al., 1986; Dahling and Safferman, 1979). The appearance of viruses in recreational or drinking water has also been linked with sludge disposal (Rao et al., 1986). Enteroviruses have been shown to be associated with solids that aid in the transport of these viruses in ocean sediment and in soils following land disposal of sludge. These solids- associated enteroviruses can then be dislodged from the substrate by rainwater or by water turbulence. Once the viruses are dislodged, the original aggregate of viral particles can then contaminate drinking water or recreational water (Rao et al., 1986).

2.3.2 Physical Description of the Viruses in Water

The enteroviruses share physical characteristics; these characteristics have been summarized in Table 2-1 and also discussed in subsections under each member of the enterovirus group.

2.3.3 Host Range

Man is the natural host for the human enteroviruses and hepatitis A, although some reports indicate domestic animals such as dogs as well (Grew et al., 1970; Clapper, 1970). In laboratory studies however, polioviruses can infect monkeys and chimpanzees by the oral, intraspinal and intracerebral routes. Coxsackievirus group A and group B can infect suckling mice but will produce different distinctive lesions. Echovirus can infect rhesus monkeys and newborn mice. HAV can infect chimpanzees and some monkey species (Melnick, 1996a; EPA, 1985).

2.4 Epidemiology

2.4.1 Epidemiological Evidence for Waterborne Transmission of Viruses

According to Every and Dawson (1995), a microorganism has to meet two criteria to be implicated as the etiological agent. It must be found in significantly higher numbers in sick individuals than in normal individuals. The microorganism should also be found in the source (water), or there should be an appropriately timed event that would allow the agent to bypass the treatment system.

Numerous reported waterborne outbreaks have been associated with gastroenteritis due to a viral agent (CDC, 1996a). Contaminated drinking water was implicated as the source of infection. These outbreaks are discussed in detail in the outbreak section of this chapter. The specific water systems identified in the reported outbreaks such as community, noncommunity, and individual systems and water source such as ground water and surface water are also discussed in detail in the outbreak section.

2.4.2 Seasonal Distribution of Viruses in Water

The prevalence of enteroviruses in the United States is seasonal, occurring in late summer and fall (Melnick, 1996b). Poliovirus, however, can occur year round, particularly in communities that have active vaccination programs. The seasonality of HAV has been reported by Hedberg and Osterholm (1993). A high incidence of HAV has also been reported to occur in autumn. Coxsackievirus has been reported to be more prevalent in the late summer and fall (Kogan et al., 1969).

2.5 Waterborne Outbreaks of Viral Diseases in the United States

2.5.1 Disease Outbreak Surveillance System Criteria

A waterborne disease outbreak as defined by the CDC is an incident in which:

1) Two or more persons experience a similar illness after the consumption of drinking water or after exposure to water used for recreational purposes.

2) Epidemiologic evidence must implicate water as the probable source of the illness (CDC, 1996a).

The surveillance system for a waterborne disease outbreak is similar to that of a food-borne disease outbreak. In both systems, the unit of analysis is an outbreak and not an individual case of a particular disease as in other systems. ***Two persons or more must experience an illness*** after ingesting drinking water. However, the criterion for two persons is waived for single cases of laboratory confirmed, primary meningoencephalitis and for single cases of chemical poisoning if water quality data indicate contamination by the chemical. In addition, when primary and secondary cases are distinguished in an outbreak report, only the primary cases are included in the outbreak report form. Outbreaks that are due to contamination of water or ice at the point of use are not classified as waterborne disease outbreaks (CDC, 1996a).

Waterborne disease outbreak information has been collected since 1920 by the United States Public Health Service. This responsibility was transferred to CDC in 1966 (Lippy and Waltrip, 1984). In 1971, EPA and CDC joined in a collaborative effort to improve the reporting of waterborne illness (CDC, 1996a; Lippy and Waltrip, 1984). It is important to note that the reporting of a waterborne disease outbreak to the Federal Government is voluntary (Calderon and Craun, 1998). Since 1971, EPA and CDC have maintained a cooperative effort in the surveillance and reporting of waterborne outbreak occurrence and their causes and this information is made available annually. The health departments of individual states in the United States are required to report water related disease outbreaks to CDC. In addition, the Health Effects Research Laboratory of EPA contacts all the state water supply agencies to obtain information on waterborne disease outbreaks annually. CDC however, indicates that the number of reported waterborne disease outbreaks represents only a fraction of the total number of occurrences (CDC, 1996a).

2.5.2 Outbreak Reports

The CDC surveillance reports from the collaborative effort's inception in 1971 to the present reveal that the highest number of drinking water associated outbreaks in the United States consistently has been due to AGI of unknown etiological agent. This section of the document examines the CDC surveillance reports from inception to 1994. Some specific years 1991-1992, and 1992-1993 are also examined. The outbreak associations are considered separately by etiologic agent, water system, water supply, and type of deficiency. The most recent surveillance report for 1995-1996 has been included. Cases of illness, hospitalization, and death from outbreaks for all etiological agents are also presented.

2.5.2.1 Etiologic Agent-Associated Outbreaks

The CDC national surveillance data (1996a) reveal that for a period spanning 24 years, from 1971 to 1994, the highest number of waterborne disease outbreaks associated with drinking water was due to AGI of unknown etiology (see Figure 2-1). Only in about 50% of the outbreaks

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1.0 Executive Summary

The Office of Science and Technology (OST) has prepared and revised the Drinking Water Criteria documents that will support the Office of Water's Ground Water Rule (GWR) and Surface Water Treatment Rule (SWTR). Waterborne pathogenic enteric viruses are among the microorganisms to be regulated by these rules. The SWTR requires water systems that use surface or ground water that is under the direct influence of surface water to (a) disinfect their water and (b) filter their water or meet criteria for avoiding filtration. Under this rule viruses must be removed or inactivated at a 99.99% (4 logs) level by meeting the residual concentration and disinfectant contact time values in the rule.

Four of the enteric viruses, namely, coxsackievirus, echovirus, calicivirus, and adenovirus, have also been included among the microorganisms of concern on the Environmental Protection Agency (EPA) Drinking Water Contaminant Candidate List (CCL). The Safe Drinking Water Act (SDWA) amendments of 1996 require EPA to publish a list of contaminants, which at the time of publication are not subject to any proposed or promulgated national primary drinking water regulation (NPDWR), that are known or anticipated to occur in public water systems and which may require regulations under the SDWA [section 1412(b)(1)].

The enteric viruses are viruses that multiply in the gastrointestinal (GI) tract of man. These viruses have been shown to cause a variety of diseases in humans, ranging from poliomyelitis, to heart disease, encephalitis, aseptic meningitis, hepatitis, hand-foot-and-mouth disease (HFMD), gastroenteritis, and diabetes mellitis. Enteric viruses are excreted in the feces of infected humans in numbers as high as 10^6–10^{12}/gram of feces.

A drinking water draft criteria document on enteric viruses was originally developed in 1985. The document now has a 15-year gap in information on the current scientific knowledge concerning waterborne pathogenic viruses. An updated virus criteria document is essential for the preparation of EPA's notice of availability to the stakeholders, states, and the general public, since this document will support the GWR and SWTR mentioned above.

Two drinking water criteria documents for viruses (EPA/822/R/98/042; EPA/822/R/98/043) have been developed by EPA to update information in the original criteria document. These documents contain new and updated information on various aspects of our current knowledge of waterborne enteric viruses, including their occurrence in source waters and sewage, outbreaks, health effects, minimum infectious dose, risk assessment, recovery and detection methods, and treatment control. The first of these documents (EPA/822/R/98/043) addresses the enteroviruses including: ***poliovirus, coxsackievirus group A, coxsackievirus group B, echovirus, enterovirus types 68, 69, 70, 71,*** and ***hepatitis A (formerly enterovirus type 72),*** which recently has been transferred to a newly created genus, called ***Hepatovirus.*** The second virus document (EPA/822/R/98/042) addresses eight other waterborne enteric viruses: ***adenovirus, astrovirus, reovirus, rotavirus, calicivirus,*** including ***Norwalk virus, small round structured viruses (SRSVs),*** and ***hepatitis E virus.***

The present document (EPA/822/R/98/043) addresses enteroviruses and hepatitis A and has been organized in 11 chapters. The table of contents outline from the 1985 document was followed for ease of cross-reference, although a few redundant topics were eliminated. A new chapter on water treatment has been added. The reader should note the difference between two terms, ***enterovirus*** and ***enteric virus,*** used throughout this document. The terms are not interchangeable, i.e., all enteric viruses are not enteroviruses. An enteric virus is defined, functionally, as a virus that multiplies in the GI tract of humans. All of the 12 waterborne viruses which are the subject of the two drinking water criteria documents are enteric viruses. An enterovirus belongs to a subgroup of enteric viruses in the genus *Enterovirus* that share similar morphological and genetic properties.

All of the enteroviruses, along with hepatitis A viruses, are shed in human feces and therefore occur in domestic sewage. There are numerous reports of their occurrence in both waste water and waste water-contaminated surface water. Outbreaks and epidemics have been associated with the presence of enterovirus in water with serious worldwide consequences. Both surface and ground water contamination have been linked to many of these outbreaks involving gastroenteritis and other illnesses. Reports indicate that most of the reported waterborne outbreaks have been associated with ground water even though this source had been believed to be relatively free from contamination due to natural filtration by soil layers, which act as barriers to microbial pollutants. Virus migration has been demonstrated in the soil subsurface for distances of 1,000 m or more, facilitating virus contamination of aquifers that provide drinking water to the public. EPA studies, as well as several others, indicate that a significant number of ground water sources show evidence of fecal contamination. This is the principal rationale for the requirement for ground water disinfection under the GWR.

The discussion on outbreaks addresses those occurring primarily in the United States. Many of these outbreaks have been shown to be associated with waterborne transmission. Waterborne disease outbreaks in the United States associated with treatment deficiencies in water supply have also been reported. When such deficiencies lead to EPA "boil water" advisories for sensitive subpopulations, as happened in the Washington, DC, area recently, consumer confidence in our water supply can be eroded, thereby increasing the number of consumers who turn to bottled water as a drinking water source, even after the treatment deficiencies are corrected.

There is a worldwide distribution of waterborne disease outbreaks. Some devastating outbreaks occurring outside the United States, and outbreaks in countries with treatment systems similar to those of the United States, are also discussed. Outbreak reports are not comparable as there were numerous reports retrieved for this document concerning waterborne outbreaks occurring in developing countries having insufficient or no treatment control systems. It has been estimated that the occurrence of enteric viruses in sewage in developing countries may average 100 to 1,000 times higher than levels seen in the United States. This document therefore notes only a few of the outbreaks from developing countries, but discusses the health effects known to occur worldwide regardless of treatment control systems.

It is important, however, that we remain cognizant of the fact that outbreaks outside of the United States can have worldwide implications, particularly in light of increased global cooperation and interactions. International travel is increasing, and it is conceivable that viruses can be exported rapidly across country borderlines by infected travelers. In addition, the escalating influx of immigrants from developing and war-ravaged countries having inadequate treatment systems is an important factor in the spread of imported waterborne viral diseases. With the United States the only superpower remaining in the world, American troops are being sent on peacekeeping missions around the world. A global partnership and collaboration with developing countries regarding waterborne outbreaks is needed to rapidly identify emerging or reemerging strains of infectious pathogens that could pose a threat both to the United States and to the world at large.

The problem of waterborne diseases continues to be exacerbated by the high percentage of acute gastrointestinal illness (AGI) of unknown etiology. It is of significant concern that close to 50% of all waterborne disease outbreaks in the United States are due to AGI caused by unknown agents. Given isolation method limitations, it is reasonable to speculate that some of the AGI of unknown origin may very well be due to viruses. There is a speculation that the unknown etiological agents may be of viral origin, because the disease patterns support this speculation. But the evidence for this is inconclusive. Technological methods for bacteria are well established, and bacteria are well known and can be easily detected. The detection of viruses, on the other hand, is difficult and complex.

The U.S. Centers for Disease Control and Prevention (CDC) indicates that the number of reported waterborne disease outbreaks represents only a fraction of the total number. It is not surprising that waterborne disease outbreaks are grossly under-reported, especially when one examines the CDC criteria for an outbreak. In order to be recorded an outbreak, two or more persons must experience a similar illness after the consumption of or use of water intended for drinking. Epidemiological evidence must implicate water as the source of illness. Factors that have been listed as contributing to the nonreporting of outbreaks include budget and laboratory resources, lack of physician interest, and consumer awareness. Another factor to consider is embarrassment. Many affected people may be unwilling to talk about a little “diarrhea” episode that may disappear in a few days. Since only two people need manifest symptoms to be considered an “outbreak,” it is likely that embarrassment may account for a significant number of cases that go unreported. Therefore, a decrease in reported outbreaks may not be an actual decrease. A better surveillance system obviously is needed at the local level to accurately track outbreaks.

The awareness of virus occurrence in water has increased with the improvements in technology for viral recovery. This in turn has led to greater concerns regarding implications of virus presence in water. In monitoring waterborne viruses, a major problem has been the concentration and enumeration of large volumes of virions in raw and finished water. Because of their small size and low numbers, accurate assessments have been difficult. Detection of viruses in water sample volumes ranging from a few to 100 liters has remained a major challenge. Virus recovery methods in existence prior to 1985 include filter adsorption-elution, adsorption to inorganic precipitates, polyelectrolytes, minerals, clays, glass beads, ultrafiltration, hydroextraction, and reverse osmosis. Since that time, continuous immunomagnetic capture, continuous flow centrifugation, cross-flow filtration, and vortex flow filtration have emerged as new technologies for improved virus recovery. The efficiency of these methods, however, varies from 20% to 80%, even when relatively high concentrations of virions are present in water samples. With those percentages of variability in recovery, human risk associated with finished drinking water sources becomes more daunting in light of the fact that infective doses for human enterovirus infection could be as low as one to four infectious particles.

Selective and sensitive immunological methods for virus detection have emerged recently, but they are frequently time consuming, require specialized training, and are labor intensive. Cell culture methods, although available for several decades and a proven way for determining the infectivity of viral particles, are also slow, require specialized training, and are labor intensive. In addition, some waterborne viruses such as coxsackieviruses and Norwalk virus still cannot be cultivated or grow poorly in cell culture. New cell lines need to be investigated and developed for noncultivatable viruses.

The greatest improvements in environmental virology during the past 15 years have been in the development of virus detection methods. Polymerase chain reaction (PCR) reverse transcriptase (RT) methods in combination with other molecular technologies, however, have been developed with high specificity and sensitivity, and are proving to be very useful in the detection of all known pathogenic, waterborne viruses. Previously identified and classified microorganisms are being reassessed by molecular methods and reclassified into new genera, and unidentified microorganisms are being identified and classified based on their genomic sequences. However, the PCR method is very difficult to use with environmental samples because of inhibitory substances that interfere with the detection of viral nucleic acid. PCR, unlike the cell culture method, cannot distinguish between infectious and noninfectious particles.

As we approach the next millennium, a rising world population and its increasing demand for water have led to greater use of recycled waste water. The use of this resource, which may contain inactivated viruses, for agricultural purposes and for other human activities, has increased the risk of viral contamination of drinking water supplies. Enteroviruses have a low infectivity and it has been shown that 1–4 tissue culture infective doses can infect a person with a high probability. If this is the case, there is reason for great concern for the hazard posed by the occurrence of infectious pathogenic virus in drinking water.

The disease states of enterovirus infections are varied. They include poliomyelitis, infectious hepatitis, aseptic meningitis, heart diseases (pericarditis, myocarditis, myopericarditis, cardiomyopathy, ischemic heart disease), hand-foot-and-mouth disease (HFMD), gastroenteritis, and insulin-dependent diabetes mellitus. It is important to understand the health effects of these viruses and the resulting implications for public health. Therefore, the health effects chapter of this document presents as much evidence as is available on the general disease profiles of all the enteroviruses.

The manifestations of disease caused by waterborne viruses reflect the virulence of the particular pathogenic viral strain and the corresponding susceptibility of the infected host. Individuals with a depressed immune system, such as immuno-suppressed patients (cancer patients, organ transplant patients, AIDS patients), the elderly, and very young children, are generally at a higher risk than the normal population to infections and are consequently prone to more severe attacks and manifest the most severe symptoms. Apparent (showing clinical symptoms) and inapparent (lacking clinical symptoms) infections by enteric viruses have been demonstrated, and both must be recognized as asymptomatic individuals may continue to shed viruses in their feces and consequently infect others. The host defense systems are directly involved in determining whether the infection becomes clinical or subclinical and whether the individual may be subject to reinfection.

New approaches to microbial risk assessment by ILSI have been developed within the last few years that differ significantly from the National Academy of Sciences (NAS) framework for chemical risk assessment. Differences include pathogen-host interactions, secondary spread of microorganisms, short-term and long-term immunity, the carrier state, host animal reservoirs, zoonotic transmission, person-to-person transmission, and conditions that lead to survival, and multiplication of microorganisms (bacteria) in the environment. Various available risk models assume a random distribution of pathogenic microorganisms in water. The risk assessment of enteric viruses is limited because of lack of information on dose-response, occurrence, and exposure data. This document identifies a more quantitative risk approach for coxsackievirus type B4.

There is a question as to whether the standard bacterial indicator of fecal contamination in drinking water has outgrown its usefulness. This is because there have been numerous instances in which bacteriological drinking water standards have been met and yet gastroenteritis outbreaks due to viruses have occurred. The best indicator for the presence of pathogenic microorganisms is the pathogenic microorganism itself. However, testing for every pathogenic microorganism of concern is not feasible because pathogenic human viruses are not always easy to detect, and methods for their detection may be expensive and require specialized equipment and skilled technicians. Over the years, various alternative indicators have been proposed, such as bacteriophages, heterotrophic bacteria, *Clostridium, Klebsiella,* and *Bifidobacteria*. There is as yet no evidence that any one of the alternatives can effectively replace *E. coli* as the indicator of human fecal contamination. A surrogate for human viruses has not as yet been identified. The role that bacteriophages will play as viral indicators in the future is not clear at this time. Various studies show little correlation between the presence of bacteriophage indicators and the human viruses of concern. More research is needed to assess indicators for human viruses.

Viruses have been shown to be more resistant to treatment than bacteria. Chlorination has been the disinfection method of choice in the United States for the past several decades because of its effectiveness in destroying pathogenic microorganisms, but we now know that not all waterborne viruses are killed or inactivated by chlorine residuals commonly used for drinking water (up to 3.75 mg/L). At the same time, cancer risks associated with disinfectant byproducts such as trihalomethane have become a public health concern. Lower chlorine levels will decrease the risk posed by chlorination byproducts, but will increase the risk posed by pathogenic viruses. Conversely, an increase in chlorine concentration will reduce the risk posed by resistant pathogenic viruses but will greatly increase the risk posed by cancer-causing disinfectant byproducts. The question then becomes, ***Which risk do we trade for the other?***

Some of the effective alternative disinfection methods include chloramine, chlorine dioxide, ozonation, and UV light. Ozonation and UV light do not leave residuals to protect against recontamination events. However, chlorine continues to be the disinfection of choice in the United States.

2.0 General Information and Properties

2.1 Introduction

Viruses are obligate intracellular parasites that cannot replicate outside a host cell. Enteric viruses, however, have the ability to survive in the environment for extended periods of time. Of all the classified viruses, over 120 of them including all the enteroviruses and hepatitis A, multiply in the human GI tract. These enteric viruses are excreted by infected individuals into domestic sewage (Metcalf et al., 1995). The discharge of treated and untreated sewage into rivers and streams impacts surface waters, recreational waters, water intakes, lakes, oxidation ponds, and even shellfish beds in estuaries. Studies have shown that sewage discharge onto land can result in virus contamination of ground water. Viruses have been recovered from rivers, water intakes, and ground water that were miles away from where the initial release into water or on land had occurred. As a consequence of these discharges, disease outbreaks associated with viruses occur at frequent intervals. The type and concentration of enteric viruses present in the sewage are dependent on the community, disease incidence, water treatment, seasonality, and socioeconomic factors.

2.2 History and Taxonomy

Enteroviruses are classified as a genus within the family Picornaviridae by the International Committee on the Taxonomy of Viruses (ICTV) (ICTV, 1995). The criteria used by the ICTV for the official taxonomy of all classified viruses include morphology (shape, size, and presence or absence of envelope), nucleic acid type (RNA or DNA), and host range (human, animal, plant, fish, or bird).

The name enterovirus is derived from "entero" (intestine), the primary site of attack for these viruses. The enterovirus genus is made up of poliovirus; coxsackievirus group A; coxsackievirus group B; echovirus; enterovirus types 68, 69, 70, and 71; and several enteroviruses of lower animals, such as pigs, mice, monkeys, and cattle. Over 100 serotypes of enteroviruses have been recognized (Melnick, 1996a).

HAV, provisionally classified as enterovirus type 72, has now been transferred into a newly created genus called ***Hepatovirus*** (ICTV, 1995). The basis for this transfer involves differences in the amino acid sequence of the protein coat and the increased resistance of hepatitis A to thermal inactivation (Melnick, 1996a).

The enteroviruses share similar properties. They reside in the same habitat, the intestinal tract of humans, and are resistant to laboratory disinfectants such as alcohol and phenol. Various solvents and detergents known to destroy other viruses such as ether and deoxycholate are ineffective against enteroviruses (Melnick, 1996a).

The antigens of the enteroviruses are used to identify specific serotypes (Melnick, 1996b). However, Prabhakar et al.

(1982) reported that antigenic mutations of enteroviruses are frequent, and as high as 1 per 10,000 virions. All known enteroviruses are resistant to all known antibiotics and chemotherapeutic agents (Melnick, 1996a). Enteroviruses are thermolabile and are rapidly destroyed when exposed to a temperature greater than 50°C. Thermal inactivation of enteroviruses has been shown to be inhibited by magnesium chloride (Melnick, 1996a,b). Poliovirus is protected against thermal inactivation in the presence of magnesium chloride, and the property has been used to stabilize oral poliovirus vaccines (Melnick, 1992).

The morphological characteristics of all the enteroviruses and hepatitis A are similar by electron microscopy (EM). As a result, an electron micrograph of poliovirus can be used to represent the morphology of any enterovirus member (Williams, 1998). The characteristics of all the enteroviruses and hepatitis A are summarized in Table 2-1.

2.2.1 Poliovirus

Poliovirus is the best known and the first recognized member of the enteroviruses. It has also been one of the most studied enteroviruses in part because it produces poliomyelitis, a devastating paralytic disease of humans. The history of poliovirus is a long one, and recently was reviewed chronologically by Melnick (1996a), one of the pioneers in the elucidation of this virus since its recovery from New York City sewage in the 1940s (EPA, 1985). The work of Melnick and Sabin has contributed to our understanding of poliovirus (Melnick, 1996a).

Three serotypes have been recognized, and poliovirus type 1 is the type species for the enterovirus genus (ICTV, 1995).

2.2.2 Coxsackievirus Group A

Coxsackievirus group A is one of two groups of coxsackieviruses that have been described. Coxsackievirus group A was first discovered by Dalldorf in 1948, and it derives its name from Coxsackie, a town in New York, where it was first isolated from a patient (Melnick, 1996a). There are 23 recognized serotypes of coxsackievirus group A (ICTV, 1995).

TABLE 2-1
Characteristics of Enteroviruses and Hepatitis A Virus

Enteroviruses						Hepatovirus
Virus	**Poliovirus**	**Coxsackie group A**	**Coxsackie group B**	**Echovirus**	**Enterovirus types 68, 69, 70, 71**	**Hepatitis A virus**
Number of serotypes	3	23	6	31	4	1
Genome	ssRNA	ssRNA	ssRNA	ssRNA	ssRNA	ssRNA
Size	27–30 nm	27–30 nm	27–30 nm	27–30 nm	27–30 nm	27 nm
Capsid	60 subunit icosahedron	60 subunit icosahedron	60 subunit icosahedron	60 subunit icosahedron	60 subunit icosahedron	60 subunit icosahedron
Virion	unenveloped	unenveloped	unenveloped	unenveloped	unenveloped	unenveloped
Buoyant density in CsCl	1.33–1.45 g/cm^{-3}	1.33–1.45 g/cm^{-3}	1.33–1.45 g/cm^{-3}	1.33–1.45 g/cm^{-3}	1.33–1.45 g/cm^{-3}	1.33–1.45 g/cm^{-3}
Morpho logy	featureless	featureless	featureless	featureless	featureless	featureless

Source: Williams, 1998; ICTV, 1995; Melnick, 1992, 1985.

2.2.3 Coxsackievirus Group B

Coxsackievirus group B was discovered by Melnick and was first isolated from a patient in Connecticut (Melnick, 1996a). It was described in 1949, a year after the discovery of coxsackievirus group A. Coxsackievirus group B has six recognized serotypes (ICTV, 1995).

2.2.4 Echovirus

Echovirus derives its name from the acronym of its full name, ***Enteric Cytopathogenic Human Orphan*** virus. Thirty-one echovirus serotypes have been described, and they are numbered sequentially from 1 through 31. Three of the serotypes have been reclassified. Echovirus type 10 has been reclassified as a reovirus, and type 28 has been reclassified as a rhinovirus. Echovirus type 34 is reclassified as a variant type of coxsackievirus A 24 (Melnick, 1996a).

2.2.5 Enterovirus Types 68, 69, 70, and 71

New members of the *Enterovirus* genus are no longer subclassified as coxsackievirus or echovirus but instead numbered sequentially because of the variability in the biological properties such as the production of pathological changes in newborn mice. This numerical numbering system will be retained for these enteroviruses until sufficient and definitive data become available to place them into an appropriate subgroup (Melnick, 1996a; Kibrick, 1964).
Only one serotype has been recognized for each numbered enterovirus (ICTV, 1995).

2.2.6 Hepatitis A Virus

HAV was formerly classified as enterovirus type 72 in the genus *Enterovirus*. It is now classified in the genus *Hepatovirus*. HAV shares many properties with all the viruses in the name from Coxsackie, a town in New York, where it was first isolated from a patient (Melnick, 1996). There are 23 recognized serotypes of coxsackievirus group A (ICTV, 1995). *Enterovirus* genus (see Table 2-1). It is, however, more temperature and acid stable than the enteroviruses. An HAV particle is 27 nm in diameter, is nonenveloped, and has an icosahedral symmetry. It has a single-stranded RNA genome that contains 7,500 nucleotides. The RNA strand is positive and thus serves as its own messenger RNA (Levinthal and Ray, 1966). Only one serotype has been described for hepatitis A (ICTV, 1995).

2.3 Viruses in Water

2.3.1 Sources of Viruses in Water

Human enteric viruses are excreted in high numbers (10^8–10^{12} particles/g of feces) by infected individuals and consequently are present in waters contaminated by fecal material (Abbaszadegan et al., 1998; Abbaszadegan and DeLeon, 1997; Payment, 1993). Treated waste water effluent from sewage treatment plants contains inactivated as well as infectious viruses that are discharged into surface water (Tani et al., 1995; Black and Finch, 1993; Bosch et al., 1986; Dahling and Safferman, 1979). The appearance of viruses in recreational or drinking water has also been linked with sludge disposal (Rao et al., 1986). Enteroviruses have been shown to be associated with solids that aid in the transport of these viruses in ocean sediment and in soils following land disposal of sludge. These solids- associated enteroviruses can then be dislodged from the substrate by rainwater or by water turbulence. Once the viruses are dislodged, the original aggregate of viral particles can then contaminate drinking water or recreational water (Rao et al., 1986).

2.3.2 Physical Description of the Viruses in Water

The enteroviruses share physical characteristics; these characteristics have been summarized in Table 2-1 and also discussed in subsections under each member of the enterovirus group.

2.3.3 Host Range

Man is the natural host for the human enteroviruses and hepatitis A, although some reports indicate domestic animals such as dogs as well (Grew et al., 1970; Clapper, 1970). In laboratory studies however, polioviruses can infect monkeys and chimpanzees by the oral, intraspinal and intracerebral routes. Coxsackievirus group A and group B can infect suckling mice but will produce different distinctive lesions. Echovirus can infect rhesus monkeys and newborn mice. HAV can infect chimpanzees and some monkey species (Melnick, 1996a; EPA, 1985).

2.4 Epidemiology

2.4.1 Epidemiological Evidence for Waterborne Transmission of Viruses

According to Every and Dawson (1995), a microorganism has to meet two criteria to be implicated as the etiological agent. It must be found in significantly higher numbers in sick individuals than in normal individuals. The microorganism should also be found in the source (water), or there should be an appropriately timed event that would allow the agent to bypass the treatment system.

Numerous reported waterborne outbreaks have been associated with gastroenteritis due to a viral agent (CDC, 1996a). Contaminated drinking water was implicated as the source of infection. These outbreaks are discussed in detail in the outbreak section of this chapter. The specific water systems identified in the reported outbreaks such as community, noncommunity, and individual systems and water source such as ground water and surface water are also discussed in detail in the outbreak section.

2.4.2 Seasonal Distribution of Viruses in Water

The prevalence of enteroviruses in the United States is seasonal, occurring in late summer and fall (Melnick, 1996b). Poliovirus, however, can occur year round, particularly in communities that have active vaccination programs. The seasonality of HAV has been reported by Hedberg and Osterholm (1993). A high incidence of HAV has also been reported to occur in autumn. Coxsackievirus has been reported to be more prevalent in the late summer and fall (Kogan et al., 1969).

2.5 Waterborne Outbreaks of Viral Diseases in the United States

2.5.1 Disease Outbreak Surveillance System Criteria

A waterborne disease outbreak as defined by the CDC is an incident in which:

1) Two or more persons experience a similar illness after the consumption of drinking water or after exposure to water used for recreational purposes.

2) Epidemiologic evidence must implicate water as the probable source of the illness (CDC, 1996a).

The surveillance system for a waterborne disease outbreak is similar to that of a food-borne disease outbreak. In both systems, the unit of analysis is an outbreak and not an individual case of a particular disease as in other systems. ***Two persons or more must experience an illness*** after ingesting drinking water. However, the criterion for two persons is waived for single cases of laboratory confirmed, primary meningoencephalitis and for single cases of chemical poisoning if water quality data indicate contamination by the chemical. In addition, when primary and secondary cases are distinguished in an outbreak report, only the primary cases are included in the outbreak report form. Outbreaks that are due to contamination of water or ice at the point of use are not classified as waterborne disease outbreaks (CDC, 1996a).

Waterborne disease outbreak information has been collected since 1920 by the United States Public Health Service. This responsibility was transferred to CDC in 1966 (Lippy and Waltrip, 1984). In 1971, EPA and CDC joined in a collaborative effort to improve the reporting of waterborne illness (CDC, 1996a; Lippy and Waltrip, 1984). It is important to note that the reporting of a waterborne disease outbreak to the Federal Government is voluntary (Calderon and Craun, 1998). Since 1971, EPA and CDC have maintained a cooperative effort in the surveillance and reporting of waterborne outbreak occurrence and their causes and this information is made available annually. The health departments of individual states in the United States are required to report water related disease outbreaks to CDC. In addition, the Health Effects Research Laboratory of EPA contacts all the state water supply agencies to obtain information on waterborne disease outbreaks annually. CDC however, indicates that the number of reported waterborne disease outbreaks represents only a fraction of the total number of occurrences (CDC, 1996a).

2.5.2 Outbreak Reports

The CDC surveillance reports from the collaborative effort's inception in 1971 to the present reveal that the highest number of drinking water associated outbreaks in the United States consistently has been due to AGI of unknown etiological agent. This section of the document examines the CDC surveillance reports from inception to 1994. Some specific years 1991-1992, and 1992-1993 are also examined. The outbreak associations are considered separately by etiologic agent, water system, water supply, and type of deficiency. The most recent surveillance report for 1995-1996 has been included. Cases of illness, hospitalization, and death from outbreaks for all etiological agents are also presented.

2.5.2.1 Etiologic Agent-Associated Outbreaks

The CDC national surveillance data (1996a) reveal that for a period spanning 24 years, from 1971 to 1994, the highest number of waterborne disease outbreaks associated with drinking water was due to AGI of unknown etiology (see Figure 2-1). Only in about 50% of the outbreaks

*

was